Study of the audio characteristics of mobile phones in the context of transmission of biomedical signals converted into sound

Ivo Tsvetanov Iliev, Borislav Todorov Ganev, Ivan Krasimirov Kanev
Department of Electronics, Faculty of Electronic Engineering and Technologies
Technical University of Sofia
8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria
{izi, b_ganev} @tu-sofia.bg, ikanev@icloud.com

Abstract – **The remote patient monitoring system has become a research hotspot in recent years. Using ICT and some wearable technology, it is possible to monitor the user's health condition in real-time. At the same time, the development of communication technologies with higher density of the communication channels is associated with increasingly occurring collisions. One simple approach using mobile phone (GSM) for patient's data transmission of audio transformed biological signals is discussed in this paper. The results of performed experimental laboratory tests for determining the acoustic characteristics of GSM devices are presented.**

Keywords – **remote patient telemetry, GSM remote monitoring, telemedicine.**

I. Introduction

Remote patient monitoring (or mobile patient monitoring, or ambulatory monitoring or patient telemetry) is a well-known clinical practice expanding the clinician's ability to understand what is happening in a patient's body over time. In an extensive study of the International Society for Holter and Non-invasive Electrocardiology (ISHNE) (*Jonathan S. et al. 2017*), the specific aspects of ambulatory monitoring and mobile ECG telemetry have been analyzed in detail, including basic features: duration of the telemetry, types of electrodes, construction design of the apparatus part, the transmission of the data from the registering device to the end user (a central station or a medical expert analysis module), the data processing algorithms, data protection methods, etc.

The typical concept realization of mobile patient monitoring systems consists of portable micro power device with battery supply that is worn by the patient during the study. It registers and processes one or several biomedical signals and/or parameters. Depending on the purpose and the duration of the study in different configurations, short-term recordings are typically collected:

- At certain time-intervals or on request (external event recorder);
- Continuous recording (standard holter);
- Recording of short diagnostically valuable episodes over a long monitoring period (external loop recorder);
- Recognizing life-threatening conditions and recording of the underlying ECG episodes together with alarm generation (mobile cardiac ambulatory telemetry).

The data transfer from the patient module to the end receiver is performed through the mobile networks (GPRS, UMTS, 4G, 5G) of the telecommunication operators or through the networks of the Internet providers. The end data collector could be a special data server with an authorized access or a virtualized software-defined data center (cloud), a central data collection station in a hospital, a PC, or the smartphone of the attending physician. A significant advantage of these is the relatively easy WPS (Wireless Protected Setup) procedure for joining the network, the availability of standardized communication protocol MQTT (Message Queue Telemetry Transport) for transmitting data to the cloud, different levels of system communication setup QoS (Quality of Service) as well as encrypted SSL/TLS protocol. But it should be borne in mind that the network controller providing IoT connectivity consumes current about 60-80 mA in receiver mode and up to 250-300 mA in transmission mode that severely restricts the application of this type of communication in mobile sensor systems with autonomous power supply, such as the telemetry patient monitors.

Another specific problem is associated with the use of modern means for communication by the main telemetry target group of patients, such as the elderly with their typically high incidence of cardiovascular diseases (*Vasek P. et al. 2016, Seitzer M. 2016*). Possible solutions are re-learning and improving skills (*Zoe R. et al. 2010*) or creating easily usable devices with high reliability.

Thus, the idea of using telemetry cardiac systems based on the most common approach for remote connectivity – the sound communication, was promoted. In fact, this is the most easily feasible solution supported by almost all modern means of communication. Beneficially, this type of communication does not require special data protection actions (encryption) because it uses the standard transfer channels provided by the telecommunication companies.

In order to implement this idea in practice, it is necessary to transform the electrocardiogram into sound after that translate it through GSM module. The ECG audio transformation was presented in several publications as a cardiac rhythm analysis approach (*Mihalas G. et al. 2012, Blanco L. et al. 2017*) or as a means of sound interpretation for recognition of specific cardiac pathologies in long-term recordings (*Kather J. et al. 2017*).

As a key element in the process of remote communication, it is necessary to study the acoustic characteristics of the GSM in order to determine its ability to accept, process and transmit the sonified ECG. The research was conducted in laboratory conditions, and below in the article the test setup and the obtained results are presented.

II. EXPERIMENTAL SETUP

An experimental test setup was built for the detailed performance study of the GSM audio channel (Fig. 1). The setup is realized on the basis of the Rigol DG4062 and Rohde & Schwarz HMO1022. The control of the setup and the measurement procedures is executed by computer, in LabVIEW environment.

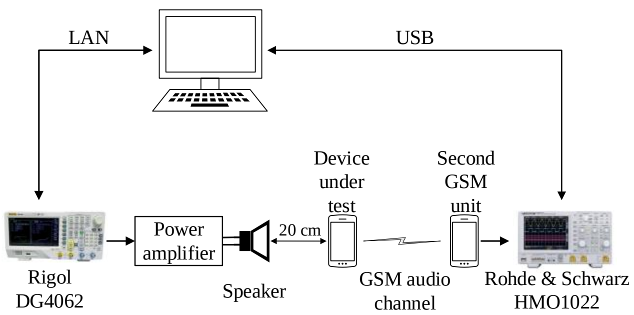

Fig. 1. Experimental setup

Rigol DG4062 is a 60 MHz waveform generator using to generate a sine wave with controlled frequency and amplitude. Rohde & Schwarz HMO1022 is a 2 channel, 100 MHz digital oscilloscope. The signal from the output of the generator is fed to an audio amplifier and a loudspeaker. The generated sound is recorded by a tested GSM and transmitted via an audio channel to the second GSM, the audio output of which is connected to the oscilloscope.

The block diagram of virtual frequency response analyser (synthesized in LabVIEW environment), related to the management of the processes of audio signal generation as well as registration, processing and visualization of the transferred audio signal is presented in fig. 2.

The function generator (Rigol) is connected to the computer as an external network device. The functional elements in diagram, relating to the generation of the audio signal, perform the following functions:

- adjustment of the amplitude of the generated audio signal.
- selection of the frequency range of the generated audio signal;

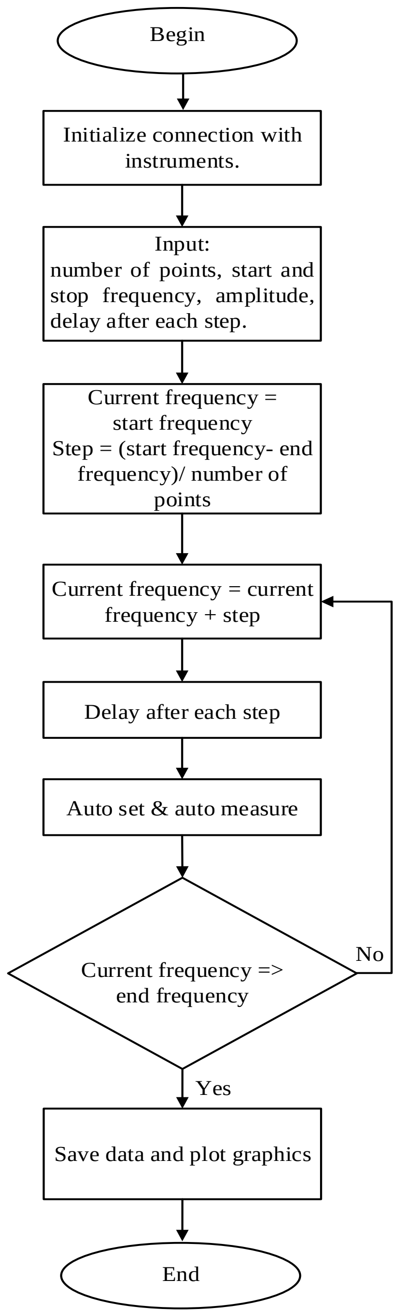

Fig. 3. Working algorithm of the virtual analyser

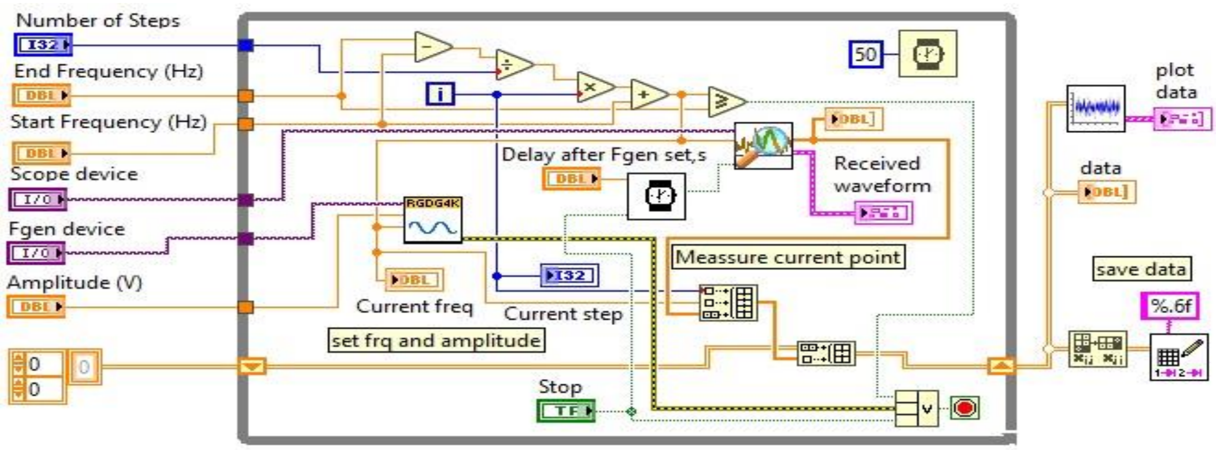

Fig. 2. Block diagram of virtual frequency response analyser

- selection of the step of changing the frequency within the frequency range;

The recording device (Rohde & Schwarz) is connected to the computer via an USB interface. The functional elements in diagram, relating to the generation of the audio signal, perform the following functions:

- reading the data from oscilloscope;
- calculation the amplitude of the registered sinusoidal signal;

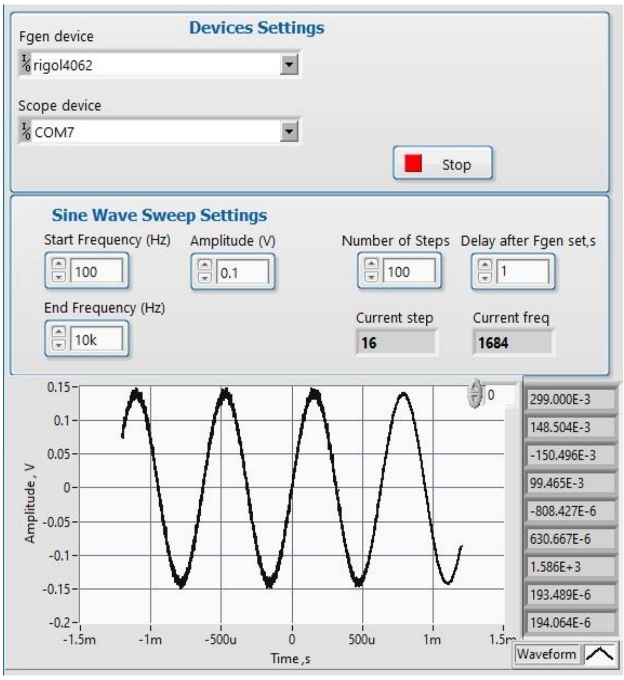

Fig. 4. Front panel for control of the testing process

- synthesis the frequency response of the tested GSM, after the end of generation- transmission cycle of the full spectrum of audio frequencies.

The main algorithm presenting the measurement process is shown in Fig. 3.

For specific laboratory tests, appropriate software was synthesized, facilitating the process of setting up and performing the steps described in the working algorithm. The corresponding front panel for driving of the virtual frequency response analyser is shown in Fig. 4.

III. Results

The presented results are from performed tests to determine the frequency response of the audio modules of six mobile phones of different classes:

- Samsung GT-I9060I
- Samsung SGH-C140
- Xiaomi Mi A3
- iPhone XS
- Samsung Note 9
- Sony Ericsson LT18i

The corresponding graphs are presented in fig. 5.

As can be seen from the graphs, there is a clearly defined bandwidth in the range of 0.3 kHz - 3.8 kHz. The plateau in the bandwidth is approximately smooth. Some peaks are seen in more expensive mobile phone models. Our hypothesis is that these peaks may be due to the occurrence of acoustic interference (reflections, reverberations, etc.) and the application of more precise algorithms for their elimination in newer models of tested devices.

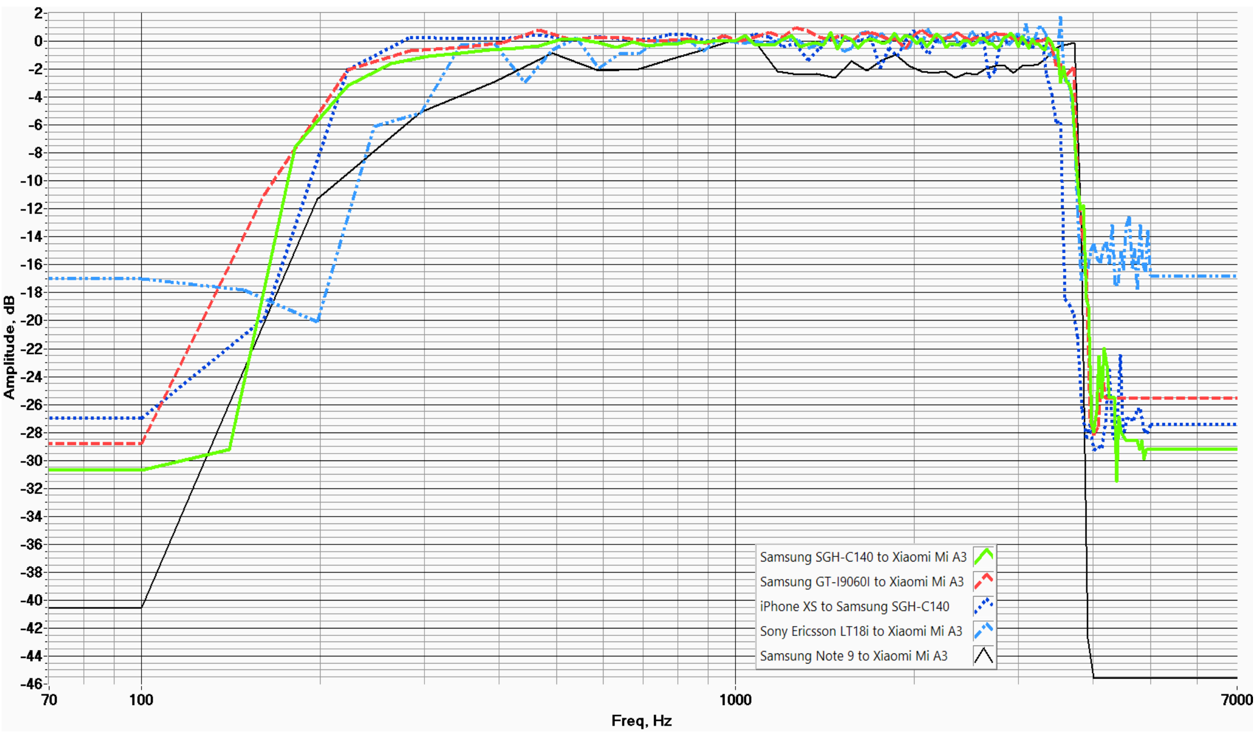

Fig. 5. Frequency response of the tested mobile phones

IV. Discussion and Conclusion

The telemetric data link avoids direct connections to the stationary recording or monitoring equipment, which are sometimes embarrassing and restrictive of the patients freely move. They can be monitored in their natural environment and during work. A commonly used approach to modern ambulatory systems is the data transmission at a close distance from the patient module to a mobile device (GSM) or stationary station (Gateway), and a subsequent retransmission to the remote end-receiver. For close communication, low-consumption interfaces (e.g. Bluetooth Low Energy, SimplisiTI, LoRa) are used. However, in such a conversion, the problems arise in establishing the connection and maintenance of the communication channel. Even at home, if the distance between the source and the receiver is large or there are partitions (reinforced concrete walls), the communication might not be established.

One possible approach to overcome the problems of short-range data transmission is the elimination of low-power communication interfaces. An option for this purpose is to convert the registered biosignal (biosignals) to audio signal and to transmit it via GSM as a standard voice message. Experimental studies and the obtained results have shown that such a translation is possible in the bandwidth 0.3 kHz - 3.8 kHz. The sound transformation should be realized by frequency modulation of the carrier frequency (e.g. 1 kHz), in this bandwidth, with modulation frequency corresponding to the biosignal. In analogy with the 8-bit ADC conversion of the ECG, the audio transformation of ECG would result in resolution of 1Hz/div if modulation frequency is ±128 Hz. The planned upcoming studies will demonstrate the extent to which this resolution meets the requirements for remote ECG transmission, as well as how many ECG leads can be transmitted simultaneously via a mobile phone.

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